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Supplemental Material

Table S1. Complete $^{40}\text{Ar}/^{39}\text{Ar}$ data.

Table S2. Fo (=Mg/[Mg+Fe]) and Ni EPMA data for olivine profiles from the Koko Rift (Koko Crater bomb and flow, Kaupo lava flow and Kāohikaipu Island) from core to rim.

Document S3. Full description of diffusion modelling equations and boundary conditions.

Figure S4. a, b. Histograms of the forsterite (Fo) contents of olivine cores (a) and rims (b) from three Koko Rift eruptions (Koko Crater, Kāohikaipu and Kaupo). c. Forsterite transects across olivine from cores to rim for representative crystals using in the diffusion modeling. d. Zoning patterns of the Koko rift olivine compositional profiles indicating that diffusion dominated over growth (e.g., Costa et al. 2020).

Supplementary Material for “A possible sea-level fall trigger for the the youngest rejuvenated volcanism in Hawai‘i” by Jicha et al.

The supplement contains the following files:

- (1) Supplementary Document 1: Full description of diffusion modelling equations and boundary conditions

- (2) Supplementary Figure 1: a, b. Histograms of the forsterite (Fo) contents of olivine cores (a) and rims (b) from three Koko Rift eruptions (Koko Crater, Kāohikaipu and Kaupo). c. Forsterite transects from core to rim across representative olivine crystals used in the diffusion modeling. d. Zoning patterns of the Koko rift olivine compositional profiles indicating that diffusion dominated over growth (e.g., Costa et al. 2020).

- (3) Supplementary Table 1: Complete $^{40}\text{Ar}/^{39}\text{Ar}$ dataset including all isotopic data as well as all constants and correction factors used. This table is an Excel file that is separate from the Supplementary Document 1 and Supplementary Figure 1 herein.

Supplementary Document 1: Diffusion modeling equations and boundary conditions

The one-dimensional Fick's 2nd law, also called the continuity equation, was used here as it includes a time-dependence component:

$$\partial C(x, t) \partial t = D \partial^2 C(x, t) \partial x^2 \quad (1)$$

This form of Fick's 2nd law is valid for diffusivities that are concentration-independent. However, since Fe-Mg (forsterite) and Ni diffusivities that we modeled depend strongly on concentration, the expanded form of Fick's 2nd law is needed that incorporates a concentration-dependence component:

$$\partial C(x, t) \partial t = \partial D \partial x \partial C(x, t) \partial x + D \partial^2 C(x, t) \partial x^2 \quad (2)$$

where D is the diffusion coefficient in m²/second, x is the distance in meters, t is the time in seconds, C is the concentration in wt.%. The diffusivity equations for forsterite and Ni along the c-axis have been determined (e.g. Dohmen and Chakraborty, 2007) as:

$$D_{(001)}^{Fe-Mg} = 10^{-9.21} * \left(\frac{fO_2}{10^{-7}}\right)^{\frac{1}{6}} * 10^{3(0.9-X_{Fo})} * \exp\left(-\frac{20100+(P-10^5)*7*10^{-6}}{RT}\right) \quad (3)$$

$$D_{(001)}^{Ni} = 3.84 * 10^{-9} * \left(\frac{fO_2}{10^{-6}}\right)^{\frac{1}{4.25}} * 10^{1.5(0.9-X_{Fo})} * \exp\left(-\frac{220000+7*10^{-6}*(P-10^5)}{RT}\right) \quad (4)$$

where fO_2 is the oxygen fugacity in Pa, X_{Fo} is the molar fraction of forsterite in the olivine, P is the pressure in Pa, R is the gas constant and T is the temperature in Kelvin. Note that the diffusivity of Ni depends on the Fo mole fraction.

Most of the Koko Rift olivine have a simple concentration profile (i.e. single step; Fig. 1c). Thus, diffusion is assumed to be chemically homogeneous (e.g. Costa and Chakraborty, 2004). Usually, the initial concentration is taken as the extreme forsterite content in the crystal (Costa et al., 2008). If the analytical profile shows a plateau, the initial condition takes the mean value of this plateau (i.e. infinite medium). If no plateau is present, which is the case for longer diffusing times (i.e. semi-infinite medium), several initial compositions can be evaluated, which depends on: (1) the topology of the profile and (2) whether there is any correlation between the different profiles from the same sample (e.g., consistent Fo and Ni content in the core plateau).

The boundary conditions are more complicated as they may not be recorded clearly within the profile. Each crystal was evaluated to determine whether the rim was in equilibrium with the melt, which allows the boundary condition to be fixed accordingly. Profiles from the same sample were found to have similar rim or crystal-melt interface compositions. Thus, we assume that the forsterite concentration outside the crystal is constant (i.e., the melt being an infinite reservoir).

The boundary concentration is generally fixed at the rim point or the two points that surround the crystal rim location.

Diffusion modeling

Flat or stepped initial concentration profiles were assumed to partially re-equilibrate after chemical perturbation from a change in composition. The profiles were used as output constraints for diffusion models performed in a 1-D finite difference method. This method allows easy computing and permits simultaneous multi-elemental modeling of diffusion (Shea et al. 2015a). Specifically, we use the FTCS (Forward in Time Central in Space) finite difference to model the 1-D diffusion. The finite-difference method is simple to use and more adaptive for the variety of profiles measured in this study (e.g. crystal-melt, crystal core-crystal rim-melt). The FCTS finite difference is based on the space and time discretization. Equation (2) is modified and expressed as:

$$C_{i,j+1} = C_{i,j} + \Delta t \frac{C_{i+1,j} - C_{i,j}}{\Delta x} \frac{D_{i+1,j} - D_{i,j}}{\Delta x} + r [(C_{i+1,j} - 2C_{i,j} + C_{i-1,j})] \quad (5)$$

where C is the concentration of the element (i.e. Fo, Ni), Δt , Δx are the changes in time and distance for the steps, i is the distance along x, j is the time step, and $r = \frac{D\Delta t}{\Delta x^2}$.

Diffusion boundary parameters

Using known diffusivities for Fe-Mg and Ni for given conditions of P, T, fO_2 , Fe-Mg content, and crystallographic orientation (Chakraborty 2010), diffusion models yield the durations between an inferred perturbation of the magmatic system and cooling/quenching at the surface (e.g. Costa et al. 2008; Kahl et al. 2011). Model temperatures of 1163 °C were calculated using the matrix glass composition from the Koko Crater lava sample and the model of Putirka (2008). The fO_2 of Hawaiian rejuvenated magmas is known. Therefore, we used $fO_2=10^{-10}$ bar (about $\Delta QFM-1$), which was measured for Kilauea and Mauna Loa basalts (Rhodes and Vollinger 2005). Similarly, without information on pre-eruptive magma pressure conditions for the Koko Rift zone, a pressure condition relevant to typical shallow reservoirs at Hawaiian volcanoes (P~85 MPa assuming a density of 2.9 g/cm³ and a depth of 3 km) was assumed. Compositional dependence (Fe-Mg) on Fe-Mg and Ni diffusivities were accounted for in the models. The orientations of analytical transects with respect to the crystallographic axes are required in order to perform diffusion anisotropy corrections. These were obtained using electron backscatter diffraction (EBSD). Following Costa and Dungan (2005), each pair of Fo and Ni profiles were modeled

separately, as a way to evaluate the correspondence or discrepancy between the obtained timescales.

Diffusion versus growth-dominated

Previous studies (e.g., Costa and Dungan 2005; Shea et al. 2015b) have assumed that Fe-Mg and Ni zoning in olivine is related to diffusion and not fractional crystallization growth. The Koko Rift olivine show that diffusion dominated over growth. This is based on the Fo and Ni diffusion modeling, which show consistent Ni vs. Fo zoning patterns and output timescales (Fig. 3b; Supplementary Fig. 1d).

Supplementary Figures

Figure 1: **a, b.** Histograms of the forsterite (Fo) contents of olivine cores (a) and rims (b) from three Koko Rift eruptions (Koko Crater, Kāohikaipu and Kaupo). **c.** Forsterite transects from core to rim across representative olivine crystals used in the diffusion modeling. **d.** Zoning patterns of the Koko rift olivine compositional profiles indicating that diffusion dominated over growth (e.g., Costa et al. 2020).

References

- Chakraborty, S. Diffusion coefficients in olivine, wadsleyite and ringwoodite. *Reviews in Mineralogy and Geochemistry*, 72(1), 603-639 (2010).
- Costa, F., & Chakraborty, S. Decadal time gaps between mafic intrusion and silicic eruption obtained from chemical zoning patterns in olivine. *Earth and Planetary Science Letters*, 227(3-4), 517-530 (2004).
- Costa, F., Dohmen, R., & Chakraborty, S. (2008). Time scales of magmatic processes from modeling the zoning patterns of crystals. *Reviews in Mineralogy and Geochemistry*, 69(1), 545-594 (2008).
- Costa, F., & Dungan, M. (2005). Short time scales of magmatic assimilation from diffusion modeling of multiple elements in olivine. *Geology*, 33(10), 837-840 (2005).
- Costa, F., Shea, T. & Ubide, T. Diffusion chronometry and the timescales of magmatic processes. *Nat. Rev. Earth Environ.* 1, 201–214. (2020).
- Dohmen, R., & Chakraborty, S. Fe–Mg diffusion in olivine II: point defect chemistry, change of diffusion mechanisms and a model for calculation of diffusion coefficients in natural olivine. *Physics and Chemistry of Minerals*, 34(6), 409-430 (2007).
- Kahl, M., Chakraborty, S., Costa, F., & Pompilio, M. Dynamic plumbing system beneath volcanoes revealed by kinetic modeling, and the connection to monitoring data: An example from Mt. Etna. *Earth and Planetary Science Letters*, 308(1-2), 11-22 (2011).

Putirka, K.D. Thermometers and Barometers for Volcanic Systems. *Reviews in Mineralogy and Geochemistry*, 69(1): 61–120 (2008).

Rhodes, J.M., & Vollinger, M.J. Ferric/ferrous ratios in 1984 Mauna Loa lavas: a contribution to understanding the oxidation state of Hawaiian magmas. *Contributions to Mineralogy and Petrology*, 149(6), 666-674 (2005).

Shea, T., Costa, F., Krimer, D. & Hammer, J.E. Accuracy of timescales retrieved from diffusion modeling in olivine: A 3D perspective. *American Mineralogist* 100(10): 2026–2042 (2015a).

Shea, T., Lynn, K.J. & Garcia, M.O. Cracking the olivine zoning code: Distinguishing between crystal growth and diffusion. *Geology* 43(10): 935-938 (2015b).

